Practical Insights into the Design of Future Disaster Response Training Simulations

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ABSTRACT

A primary component of disaster response is training. These educational exercises provide responders with the knowledge and skills needed to be prepared when disasters happen. However, traditional training methods, such as high-fidelity simulations (e.g., real-life drills) and classroom courses, may fall short of providing effective and cost-efficient training that is needed for today's challenges. Advances in technology open a wide range of opportunities for training using computer-mediated simulations and exercises. These exercises include the use of mixed reality games and wearable computers. Existing studies report on the usefulness of these technologies for training purposes. This review paper synthesizes prior research and development of disaster response simulations and identifies challenges, opportunities, and lessons learned. Through this review, we provide researchers and designers with an overview of current practices in designing training simulations and contribute practical insights into the design of future disaster response training.

Keywords

Training, Simulation, Disaster Response, Mixed Reality, Coordination, Planning, Zero-fidelity.

INTRODUCTION AND BACKGROUND

Disaster response is a complex set of activities to mitigate the effect of an incident (U.S. Department of Homeland Security 2008). Responders are typically professionally trained, licensed practitioners who contain the impact of disasters while trying to prevent further loss of life and property (Bigley and Roberts 2001). Such response is crucial because disasters cannot be prevented entirely, but their impact can be contained and reduced. Disaster response training is essential for active responders to retain and enhance their knowledge, competence, and skill, particularly

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as new equipment and technology is adopted by different disaster management agencies (Bigley and Roberts 2001; Toups and Kerne 2007). However, traditional training methods, such as real-life simulated drills, classroom courses, online courses, and computer-mediated simulations present challenges in advancing disaster mitigation. Training in classroom settings lack realism, while real-life drills may be unavailable, costly, risky, and inconsistent. Computer-mediated simulations have often been pointed to as a means through which to provide cost-effective, high fidelity training, but the results of such training are often insignificant (Hsu et al. 2013). Advances in technology open a range of opportunities for training, including computer-based training simulations, mixed reality, virtual reality, and wearable computers.

Within computer-mediated simulations, there are many different stakeholders all interested in the success of such products. Significant resources have been invested in developing near-perfect representations of all types of training exercises. One set of stakeholders are the developers of simulations, who focus on the fidelity of such products as a means to report their effectiveness (Lif et al. 2011; Salas et al. 1998). These types of simulations operate under the assumption that the higher the fidelity of the operating environment, the more likely that users will learn (Hays and Singer 1989).

Within each of these simulators, the traditional method of examining the effectiveness of such training is to ask trainees how they felt about the simulator. What is often missing are the skills those being trained should acquire that are based on practitioner knowledge from outside those developing the simulation. For example, some simulations represent near-perfect simulations for flying fighter jets. Each of these simulations are rated highly by users and instructors; however, when users moved to actual aircraft, the knowledge these users brought with them was not significant when compared to lower fidelity exercises (Taylor et al. 1993). Other high-fidelity simulations have been created to aid train surgeons of many different kinds (e.g. (Sutherland et al. 2006)). No matter the type of surgery being simulated, the benefit of the high-fidelity digital simulation was moderate at best (Zendejas et al. 2013). Interestingly, more and more types of surgery simulation research are calling out these pieces of research saying that, like the above examples of fighter-jet training, the way evaluations are conducted are suspect (Kirkman et al. 2014).

The purpose of this paper is to provide practical insights into the design and development of disaster response simulations. This review will largely draw upon our prior work that spans over 10 years of research and development in the domain of disaster response training (Toups and Kerne 2007; Toups, Kerne, Hamilton, and Blevins 2009; Toups, Kerne, and Hamilton 2011; Toups, Hamilton, Keyes-Garcia, et al. 2015; Toups, Hamilton, and Alharthi 2016; Alharthi, Torres, Khalaf, and Toups 2017; Alharthi, Sharma, et al. 2018; Alharthi, Torres, Khalaf, Toups, et al. 2018). We contribute a set of challenges, opportunities, and lessons learned from prior research in this domain, developing insights for researchers, designers, and training organizations on the design of disaster response training simulations.

Mixed Reality, Virtual Reality, and Wearable Computers

Mixed reality and virtual reality provide a new dimension for developing efficient training simulations and games (Fischer, Jiang, et al. 2014). *Mixed realities* (MR) are systems that connect virtual and physical reality in some meaningful way through the use of networks, sensors, and databases (Benford and Giannachi 2011). These range from augmented reality, in which conformal 3D imagery is integrated with a perspective on the physical world, as with most aircraft head-up displays, to augmented virtuality, in which physical-world artifacts and spaces are integrated into a virtual world (Milgram and Kishino 1994). Mixed reality provide users with a sense of immersion and engagement with their surroundings through interacting *physically* with tangible objects in the physical reality, *mentally* with the virtual elements of the simulation, and *socially* with other users or players in both the physical and virtual environment (Hinske et al. 2007; Sharma et al. 2017).

Virtual reality (VR) is defined as "a real or simulated environment in which the perceiver experiences telepresence" (Steuer 1992). VR allow users to interact with and navigate through a computer generated three-dimensional environment, which offers highly immersive experience. These systems can simulate animations in real-time so that the user is immersed in and can control and move in the simulated virtual environment through different body and position trackers, and the use of a wearable head-mounted display for visual output (Steuer 1992).

Wearable computers are computing devices that can be worn on various locations on a person's body (Mann 1997). These devices establish constant interaction between the environment and the user and often form their own network of intercommunicating effectors and sensors. Wearable augmented reality, using wearable computers help wearers to view visual information that is overlaid onto reality (Starner et al. 1997). When input is needed, input wearable devices vary widely and can include mini-QWERTY keyboards or virtual keyboards; however, these types of explicit input modalities require visual attention, impacting mobility. Also, when output is needed, a number of interfaces exist, from full color high-resolution, or monochrome low-resolution head-mounted displays (HMDs), to wrist-worn displays (Mann 1997). All of these emerging technologies together offer opportunities for designing training simulations and games that are immersive, consistent, and effective.

Game-based Learning and Game Design

Simulations and games have been shown to be an effective tool for learning and training (Kiili 2005). Digital game-based learning provides a fun and convenient way to experiment and interact with virtual and realistic environments without real-world consequences. These type of games have been successfully used for developing different skills, such as teamwork (Alsaedi et al. 2016) and perceptual and motor skills (Green and Bavelier 2003; Tabor et al. 2017).

An important aspect of designing effective game-based learning and training simulations is to have a deep understanding of key elements of game design concepts and terminology. Salen and Zimmerman (2004) characterize games as interconnected systems of *rules* and *play*. *Rules* are the boundaries that constrain player action, the logical and mathematical structures of the game. *Play* is the freedom to make decisions within the rules. *Game mechanics* are the choices, constructed by the game designer, that a player makes, resulting in an observable outcome (Salen and Zimmerman 2004; Adams and Dormans 2012). Mechanics that are repeatedly invoked, and that affect the underlying subsystems of the game in important ways, are the *core mechanics*.

Prior Research and Development of Training Simulations

Prior disaster response training simulations address a wide range of skills including team coordination, decision making, planning, and sensemaking (Williams-Bell et al. 2015). Designers of these simulations and games need to take into consideration the challenges, opportunities, and insights from prior work. These lessons can be applied to future designs of training simulations. We provide an overview of current practices in designing training simulation.

Computer-mediated simulations using a desktop or personal computer provide training opportunities for emergency responders on different skills. The *Distributed Dynamic Decisionmaking* simulation (Silva et al. 2012) is an open-source command-and-control training simulation where participants solve problems in ambiguous situations by collaboratively managing resources. This simulation helps responders build decision-making and collaboration skills. Other computer simulations focus on developing sensemaking skills, such as the *Levee Patroller* (Harteveld et al. 2010), a single-player training game in which a player must find levee failures in a region and report them in a timely manner. It was designed to target the Dutch water authorities to help trainees make sense of risks and develop decision-making skills. While these simulations provide training opportunities, the results of such training are often insignificant, and their benefits can be limited due to their classroom settings.

With advances in technology, new opportunities for training have emerged. VR has been increasingly used in the design of training simulations. Hsu et al. (2013) provide an overview of how VR has been used for disaster preparedness training by governmental agencies and their benefits and potential drawback. In healthcare, Mantovani et al. (2003) explore the benefits of VR for surgical skills acquisition and patient care. The study suggests that these types of training can be beneficial, but should be considered only as a supplement or preoperative training. Smith and Ericson (2009) developed a VR training simulation to teach fire-safety skills to children. The result of the study shows that these types of simulations can enhance the enthusiasm of children to learn even when topics are tedious. VR can provide immersive experiences and alternative method to disaster response training, in which training is placed in a fully virtual environment. However, the immersive nature of VR can introduce different challenges when designing hands-on and face-to-face experiences (Hsu et al. 2013).

An alternative way to balance between immersion and reality in training is the use of mixed reality simulations. While the adoption of such designs in different training domains are increasing, it remains limited in disaster response training. Studies on using mixed reality games provide insights into the benefits of this approach in disaster response training. Supporting team coordination and decision-making training through the use of a scenario-based mixed reality simulation has been used, allowing responders to coordinate with each other in real-time, face-to-face and remotely, to mitigate a simulated disaster (Fischer, Jiang, et al. 2014). These types of live mixed reality simulations also provide training opportunities for human-agent coordination and collaboration (Ramchurn et al. 2016; Fischer, Greenhalgh, et al. 2017), helping responders to build advance coordination skills. Advances in personal computers and wearable technologies have the potential to enhance the design of mixed reality experiences and training (Feese et al. 2013). All of these prior studies provide innovative approaches to the design of disaster response simulations, pushing toward the adoption of advanced technologies and moving away from conventional methods of training.

Design Principle	Description
mix communication modalities	Teams should work in situations in which members spend some periods collocated and others remote, which enforces the need for learning and practicing implicit coordination and overhearing.
distribute information with uncertainty	Different members of the team should have different pieces of information, requiring team members to share and integrate information and enabling the formation of team cognition constructs.
enhance situation awareness	Audible clues should supply information about the local situation and made available to other team members through a shared audio system, engaging team members in processes of developing situation awareness.
engage developing intelligence	Team members should make informed decisions about how to collect information and need to make judgments of its authenticity and value to identify essential elements of information.
create emergent objectives	Emergent objectives may be discovered and lost as a scenario of a disaster plays out, team members may identify new objectives through gathering information.
support collaborative planning	Team members need to consider converging and diverging lines of activity that happen in the field, in which they should learn how to collaboratively plan for contingencies when activities enter exceptional states.

Table 1. A summary of the design implications and game design patterns resulted from our prior qualitative studies (Toups and Kerne 2007; Toups, Hamilton, and Alharthi 2016)

QUALITATIVE STUDIES & GAME DESIGNS

Prior research has used qualitative methods to deeply understand the nature of disaster response and look for ways to improve training and operation through system design (e.g., (Toups and Kerne 2007; Denef et al. 2008; Fischer, Reeves, et al. 2015)). One approach used in many of these studies is ethnography, in which an ethnographer is immersed in the life of people they study to uncover their practices and facilitate a deeper understanding of the complexity of the work settings (Agar 1997). For example, observations of humanitarian assistance in emergencies (Muhren and Van de Walle 2009), situational uncertainty of disaster response (Fischer, Reeves, et al. 2015), and on-line social convergence in disaster (Hughes et al. 2008), reveal how ethnographic research is useful to explore the ways people work and inform the design of systems.

Through years of qualitative observations, Toups et al. developed a deep understanding of the reality of disaster response work, which informed the design of training simulations (Toups and Kerne 2007; Toups, Kerne, and Hamilton 2011; Toups, Hamilton, and Alharthi 2016; Alharthi, Torres, Khalaf, and Toups 2017). The research team conducted a number of different observations of disaster response practices: interviews with professional emergency responders and observations of students performing burn training exercises, urban search and rescue full-scale exercises, and incident command simulations. Through these field observations, the team developed an understanding of the information-centric components of response. One of the main contributions of the prior ethnographic observations was a set of design principles in the form of implications for system design and game design patterns[1] that enable designers to develop games and simulations that engage players in disaster response style communication, coordination, planning, and sensemaking activities (Table 1). In the following, an overview of the designed games and wearable interfaces are presented as case studies of how future games can be informed by observations of disaster response practice.

The *Team Coordination Game*

The *Team Coordination Game* (*TeC*) focuses on teaching team coordination skills to student fire emergency responders. Following a *zero-fidelity* design approach (Toups, Kerne, and Hamilton 2011), characteristics of the real world are not captured in the game, focusing learning on team skills. *Zero-fidelity simulations* develop and invoke the principle of abstraction, addressing not the concrete environment, but, instead, focusing on human-information and human-human transfers of meaning, to derive design from work practice. These type of simulations shift the focus of education and reduce the costs in resources and safety.

[1] *Game design patterns* are repeatable design solutions to support the creation of games (Björk et al. 2003).

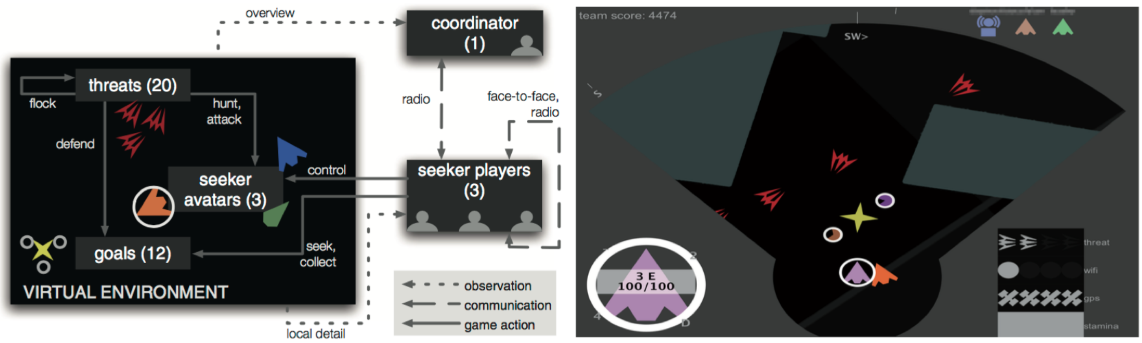

Figure 1. The *Team Coordination Game (TeC)*. Left: Game mechanics of *TeC*. Human players are to the right, communicating with one another; game entity interactions take place on the left side of the diagram, in the virtual environment. Right: screenshot of seeker view, the purple player navigate the environment searching and collecting goals and avoiding nearby threats. The visualization in the lower left shows where the avatar is located and health.

Design

In the game, players are motivated by rules that create real-time stress and information distribution, requiring a cooperative response. Participants' perspectives on the same information differ so they are reliant on one another. One of the core mechanics of *TeC* is information sharing and communication tasks. Players take on roles similar to those of fire emergency responders. The media of communication: radio and face-to-face communication, are unchanged from the source distributed cognition environment (Figure 1). Dividing information along participant roles reflects fire emergency responder work practice. Real-time stress ensures that participants must make quick decisions about what information to share, and how to share it. In this way, the play of *TeC* focuses on the human-centered aspects of team coordination.

Players take on alternative roles with different capabilities and information access. Four players make up a team: three seekers and one coordinator. Seeker players move an avatar in the virtual environment terrain, searching for goals while avoiding threats (Figure 1). A coordinator observes the virtual world with limited detail. S/he communicates with the seekers to direct them. The game environment includes threats, goals, and score to provoke a sense of crisis through game play and afford coordinated response. Because game time is limited, the team members are pushed to mutually communicate, sharing information in order to work together effectively.

Evaluation

The *TeC* game was evaluated through two user studies with both non fire emergency responders and with fire emergency responders (Toups, Kerne, and Hamilton 2011). The results of these studies show improvement in cooperative task completion, improving communication efficiency by shifting to implicit coordination. In the study, participants collected and used information from the game and from one another, reflecting fire emergency responders practice.

Designs that are based on work practice, similar to the *TeC* game, show the potential benefits of conducting field studies to gain a deep understanding of the reality of the practice. The zero-fidelity approach to the design of training simulations can lead to the design of efficacious team coordination education for crisis responders, and can open up new opportunities for training responders on other skills. This approach shows that sophisticated and glitzy high-fidelity simulations are not needed, instead, simple design and a focus on skill learning is effective.

The *Icehouse* Wearable Augmented Reality Interface

The *Icehouse* game, developed by MIT's Lincoln Lab, offers a simulation game environment in which a team of disaster responders use wearable computers and interfaces designed specifically for this game to test the usefulness of wearable interfaces in the context of disaster response (Alharthi, Sharma, et al. 2018). In this live action role playing game, players move through a physical simulated disaster space that requires team coordination and physical exertion to mitigate virtual hazards and stabilize virtual victims. The researchers developed wearable computer interfaces that integrate physiological and virtual environmental sensor data and display actionable information through an HMD (Figure 2), enabling team coordination and situation awareness. The design provides insights into the design of wearable interfaces that can be used for mixed reality training simulations.

Figure 2. The designed wearable interfaces for the disaster response mixed reality live action role playing game (*Icehouse*). 1. The team status view with player information. 2. The decision support view shows the optimal order of activities to clear a room, as well as which player should do what. 3. The interface is displayed on top of the transparent lens of the smart glasses. 4. The Sony SmartEyeglass used in the game. 5. Photos of the live mixed reality game.

Design

The design approach of these wearable interfaces was focused on enhancing situation awareness and team coordination. The designed wearable interface making use of peripheral attention and avoid displaying any information to the central of the HMD (Figure 2.3). User inputs are minimal to free hands, and only required for either switching between the information views or to account for state changes that the system cannot detect automatically. Components of the HMD include a peripheral display of the health status of teammates and activity status. This enables players to attend to the information when they need it, yet enables attention to the physical environment.

The primary value of the design came from the four information views that is provided through the smart glasses, facilitating play and communication. Using the swipe bar on the smart glasses (Figure 2.4), players could cycle through the four views to the one that was most useful to them at the time. For the smart glasses, no further interaction was required. In the following, a description of the four information views:

- *Team Status View*: this view provides situation awareness, showing the state of each team member in a compact representation at the bottom of the screen, where it minimally interferes with awareness of the nearby environment (Figure 2.3). For each player, the interface displays the player's identifier, specialty icon, exposure, room identifier, and activity status (Figure 2.1).
- *Decision Support View*: the decision support system provides players with recommendations on optimal task ordering, given data about the state of the room and using the activity priority system (Figure 2.2).
- *Map View*: this view gives a player the digitized version of the paper map provided to the players at the start of the game. In this view, the system displays a monochrome map of the game world.
- *Blank View*: the HMD did not provide a feature to turn off the display in case the user wanted to focus entirely on the environment. Thus, the designed view allow for an unobstructed view of the the physical world.

Evaluation

Members of the U.S. Coast Guard played *Icehouse* to test the performance of the wearable interface designs during a major international conference. The designed wearable interfaces were judged based on the performance of the disaster responders, including: number of victims stabilized, level of exposure, number of mitigated hazards, and feedback from the players. The results of the playtest show that using the wearable interfaces support team coordination and situation awareness. The designed interfaces provided responders with specific information about what is happening around them, allowing responders to focus on the surrounding physical environment when necessary, reducing hindrance.

The design of such wearable interfaces can provide an effective way to engage responders in training that incorporates physical aspects of disasters. These type of simulations also can be beneficial to test future disaster response wearable

Figure 3. The *Team Coordination and Planning Game (TeCP)* interface. A. The top-down map allows players to see part of the play space to develop strategies and plans. B. Players use the mouse to draw on the map to establish plans. Drawings are colored differently to be easy to identify and follow. C. The drawing is made visible directly on the gameworld, enabling its use during action gameplay, allowing players to follow their plan in real time.

technologies. The *Icehouse* wearable interface provides players with a high level of awareness of their remote teammates and their own status through awareness cues provided by each interface (Wuertz et al. 2018; Gutwin and Greenberg 2004). These wearable interfaces can be easily modified for the real world to show responders' air pack pressure, heart rate, approximate distance, and distance from a leader, making these wearable interfaces practical. Further development of wearable interfaces for disaster response practice and training is needed.

The *Team Coordination and Planning Game*

The *Team Coordination and Planning Game* (*TeCP)*, focuses on engaging players in collaborative planning activities, which are a central aspect of disaster response (Toups, Hamilton, and Alharthi 2016; Alharthi, Torres, Khalaf, and Toups 2017; Alharthi, Torres, Khalaf, Toups, et al. 2018). It is a two-player cooperative game in which players are physically separated and need to communicate and plan through the game and work together to complete objectives. A map of the gameworld provides a top-down view of the game space, allowing players to see part of the play space to develop strategies and plan. Players can also move through and manipulate objects in the gameworld to escape a maze (Figure 3). The design of this game provides insights into how future disaster simulations games can be designed. The main purpose of the design of this game is to test the benefits of different interfaces and mechanics that can then be used in the design of disaster response training simulations.

Design

The design of the game was informed by our prior research (Toups, Hamilton, and Alharthi 2016), in which the we developed game design patterns to engage players in disaster-response-style planning activities. The *TeCP* game make use of the following patterns: *collaborative planning*, *emergent objectives*, and *developing intelligence* (Table 1).

At the beginning of the game, players have a set of objectives that need to be completed. Players start by collaboratively establishing a plan using the top-down view of the gameworld, which details some of the objects in the game. Play in *TeCP* involves planning strategies to complete puzzles that require efficient collaboration. Using the annotation interfaces provided by the game, players may collaboratively draw on the map to mark locations, draw pathways, and divide tasks to complete objectives and escape the maze. Dependencies in the game force players to collaborate, creating information distribution. Specific objects in the game are assigned to one of the players; to manipulate these game objects, players need to coordinate activities and divide tasks as required.

Evaluation

The *TeCP* game was evaluated in a formal experiment with non-disaster response teams to test the impact of the different annotation interfaces on game performance and collaborative planning behavior (Alharthi, Torres, Khalaf, Toups, et al. 2018). The results of the study showed a significant improvement in performance when annotations on the map were available. The use of these interfaces helped engage teams in collaborative planning activities, which resulted in better communication and planning between players. These results suggest that using such interfaces can be helpful in engaging players in collaborative planning activities, allowing them to interact with space through a map, which can enhance spatial skills.

CHALLENGES, OPPORTUNITIES, AND LESSONS LEARNED

Designers and developers of disaster response training simulations face a number of challenges. These include conducting field studies, determining fidelity level, designing immersive experiences, ensuring usability and replayability, and evaluating training effectiveness. The following section highlights the challenges designers face, discusses opportunities to overcome them, and identifies lessons learned from prior research and development of disaster response training simulations.

Qualitative and Field Studies

Qualitative and field study research is increasingly being conducted, resulting in rich and informative studies of different cultures and practices, which help inform the design of different technologies and training solutions. These types of studies has proven to help inform the design of disaster response training simulations that are effective (Toups, Kerne, and Hamilton 2011; Fischer, Reeves, et al. 2015). However, since researchers conducting these studies are usually working with a particular community, observations can only represent a small aspect of a community's practices, thus making it difficult to generalize from the results (Pink and Morgan 2013). These limitations of field studies are also caused by live training being not always available to designers and researchers and, in most cases, dangerous and expensive[2]. To overcome some of these challenges, different approaches to conducting qualitative studies can be used, such as rapid ethnography (Millen 2000), short-term ethnography (Pink and Morgan 2013), and participatory design (Muller and Kuhn 1993). Observations using these approaches are usually undertaken in a shorter time frame, in which one or more researchers immerse themselves at the center of the action while the participants are engaged in the studied practice.

Observations over a limited time, however, may not yield sufficient insights into the everyday practice and experience of disaster response training and needs. Thus, to overcome this limitation, after conducting short-term observations, designers can engage responders in the design process through a participatory design approach (Muller and Kuhn 1993). This approach has been successfully employed in designing training simulations (e.g., Toups, Kerne, and Hamilton 2011; Fischer, Reeves, et al. 2015), which resulted in a deep understanding of disaster response practice and the design of effective training simulation. Also, live training can be inconsistent across training agencies, which limits the use of virtual training developed within a particular context. This limitation can be profound, especially when designers focus on developing high fidelity and realistic virtual simulations, which is not always necessary or more effective (G. Norman et al. 2012).

Toward Low-Fidelity Simulations

One of the main challenges in designing simulations for training is how they can be designed in such a way that they are relevant to actual practice (e.g., firefighting, search and rescue). Current games and simulations for disaster response training might not capture the actual training experience including its physical, cognitive, and social complexity (Williams-Bell et al. 2015). Prior simulations usually aspire to high-fidelity, capturing as much of the actual practice and environment as possible, in an attempt to improve practicality and effectiveness. However, including all the practice aspects into a simulation might not be always possible or even needed (Jensenab et al. 2013).This imposes challenges for designers to balance between capturing the actual experience and making the training practical, but at the same time, effective.

One way to overcome these challenges is reducing the fidelity of the developed simulation, focusing only on conceptual learning. For example, *TeC* developed a zero-fidelity simulation design approach to overcome these challenges (Toups, Kerne, and Hamilton 2011). Zero-fidelity simulations addresses not the concrete environment, but, instead, distributed cognition characteristics, abstracting alternative means by which participants can learn to perform tasks. These games help teach different skills while entertaining, so that players are encouraged to learn, providing intrinsic motivation. Zero-fidelity simulations have two main advantages over high-fidelity simulations: they are economical in that they are simpler to produce by abstracting out details that would be expensive to replicate, and those simulations usually focus on one aspect of the practice such as coordination or planning, making it possible to evaluate (Toups, Kerne, and Hamilton 2011).

[2]An example list of training courses and their costs at: `https://teex.org/Pages/Course-Catalog.aspx`

Toward Mixed Reality Training

While designing high-fidelity simulations are not necessary for effective training (Hays and Singer 1989), mixed reality can offer unique opportunities for designing training simulations that capture the different aspects of disaster response practice. Mixed reality games have received increasing attention across multiple disciplines (Pan et al. 2006), however, the adoption of such designs in disaster response simulations remains limited (Champney et al. 2016). One of the main contributions to the benefits of mixed reality is its ability to present a contextual experience that use the real physical world as a stand for the game world (Benford and Giannachi 2011). Unlike the complete artificial world of VR, mixed reality combines virtual information with a physical reality experience that takes place in physical environments. Designers do not need to simulate the environment, they simply use an existing one, such as an open field, an abandoned construction, or even an existing training ground (e.g., TEEX Disaster City[3]). The physical environment affords and constrains actions in the game through a combination of layout, size, climate, history, purpose, and/or social contracts (Sharma et al. 2017).

Using context-sensitive devices in mixed reality reduces the need for direct interaction, allowing trainees to interact naturally in the environment around them, without burdening them with complex interfaces (Mann 1997). One of the main advantages of mixed reality simulations is a strong support for both seamless and seamful interaction between the trainees and the environment (Bell 2003). Interaction in mixed reality games can be explicit (e.g., clicking a button) or implicit (e.g., passively moving) (Schmidt 2000). These interactions can be performed through different modalities, including speech, air-based gestures, vital signs, or interacting with the real world through physically moving in the environment. This enables training to move beyond the classroom, placing it in the natural context of the practice.

In disasters, responders face highly cognitive intense work and physical exertion, which are not incorporated into most virtual training simulations. In mixed reality simulations, the use of biometric and environmental sensors, location tracking, and HMDs, help to incorporate some of these aspects of disaster response into training simulations. This opens up new and innovative ways to train responders on different cognitive skills such as visual-spatial skills, navigating in a disaster scene using maps or GPS, and decision making in extreme situations. In disasters, data might be generated automatically through sensors, such as biometric sensors that can be used to determine physiological and environmental information. Designers can take advantage of these existing technologies used in disaster response and incorporate them into their designed simulation. Balancing between the use of sensors and wearable computers in mixed reality training simulation and how they can be connected to the real practice is important.

While mixed reality can help overcome many challenges and open up new ways to design training simulations, it introduces its own unique challenges. In the *Icehouse* game, the designed wearable interface relied on both data entered manually by the players and sensors from the environment, which is not always ideal. In disasters, manually entering data about the situation might hinder the responder or even reduce situation awareness of the surrounding environment, which is life-threatening. Balancing between the use of sensor data and interaction modalities in the simulation and how they can be relevant to the practice of disaster response is important. Wearable interfaces for training simulations can be designed to provide situation awareness to players. When designing wearable interfaces for mixed reality simulations, designers need to provide the right amount of information about the team and game status with minimal interferes with awareness of the nearby environment.

Despite some of the challenges with moving toward mixed reality training, new technologies and wearables are powerful and can deliver mixed reality experiences via wearable interfaces, body sensors, and mobile devices that combine the real world with sophisticated augmented information and seamless interaction. Combining these new technologies and training approaches with existing methods have the potential to improve the efficiency and effectiveness of disaster response training.

Routine Use of Training Simulations

A further issue revolves around the routine use of simulation games. Disaster response training is performed constantly over time, demanding the simulation game to be replayable. To overcome this challenge, considerations needs to be given to how the game can sustain repeated playthroughs. Gameplay in these simulations can depend on the skill of the player to an extent, which can be developed through repeated playthroughs. The evolution of players' skills needs to be tracked and presented to the player. The player can get such feedback by progressing further in the game or observing an increase in score, which can be used as an assessment metric for performance. However, this requires a game to have enough depth and scope that it requires a significant amount of time from the player

[3] https://teex.org/Pages/about-us/disaster-city.aspx

to master all the game aspects. Alternate outcomes, multiple paths to victory, achievements, increasing difficulty levels, and direct consequences for the decisions a player make within a game can make repeated playthroughs valuable (Adams and Dormans 2012).

Effective use of procedural generation content also can make simulations more replayable (Togelius et al. 2011). Creating infinite content such as emergent objectives, in which the game could gather information about the game status to trigger new objectives or quests for players can provide an extended experience (Toups, Hamilton, and Alharthi 2016).

In mixed reality simulations, however, ensuring a replayable experience can mean extensive use of technologies such as environmental sensors, body sensors, and wearable devices. These technologies need to be selected carefully, ensuring durability and ease-of-use for routine training. Designing ubiquitous mixed reality games allows players to experience mixed reality continuously in all directions in the physical environment (Sharma et al. 2017). In these types of simulations, the player can move freely to explore the environment, which can provide a highly replayable experience. Designers need to explore new and innovative ways to increase the replayability of training simulations.

Evaluation Approach

Evaluating designed training simulations poses different challenges to designers. Conducting studies with disaster responders is not always possible and in most cases difficult to arrange. Designers need to make sure that when testing the training simulation with disaster responders, the design is in a state that can benefit from the disaster responders feedback and further development. To evaluate the design, using an iterative, human-centered evaluation approach can help in assessing the effectiveness of the designs throughout the design cycle (D. Norman 2013). This involves testing the simulation with non-disaster response users first to assess the effectiveness and outcomes of the training. Focusing early in the design process of conducting multiple user studies that test different aspects of the training simulation such as the user interface, gameplay mechanics, and usability is crucial.

Evaluating the effectiveness of the training itself and the responders performance, however, remain challenging. A common approach is the use of pre- and post-training assessments and the use of different statistical measures (Farra et al. 2016). One advantage of mixed reality and the use of wearable sensors over conventional training methods is the ability to track and record the physiological data of the trainees and game statistics. These data can be then saved and/or streamed back to a central training facility, allowing for real-time evaluation of individual and group performance and assessment of the overall training effectiveness. These type of physiological and performance data can enhance the reliability and validity of the assessments and opens the door to a much wider range of training measurement instruments (Dolgov et al. 2017).

CONCLUSIONS

This review paper synthesizes prior research and development of disaster response simulations and contribute an overview of current practices in designing training simulations. Through challenges, opportunities, and lessons learned from prior development of training simulations, we provide designers with practical insights into the design of future training simulations. We believe that progress in designing disaster response simulations is needed and the use of advance technologies has a lot to offer. The potential gains from moving towards low-fidelity and mixed reality simulations can be significant: the invention of new methods of combining wearable computers with mixed reality gameplay, ensuring replayable and long-term experiences, and advance training measurement instruments are all possible.

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